Evaluation of FPD Mura Grade Using a Contrast Sensitivity Function Filter

Toshio Asano, Yuichi Morimoto and Toshimi Ikeda

Hiroshima Institute of Technology, 2-1-1 Miyake, Saeki-ku, Hiroshima 731-5193, Japan

Abstract

A novel method that can be used to evaluate mura grade on Flat Panel Displays (FPD) has been developed. This method is capable of evaluating the edge gradients of the mura. This is accomplished by converting the mura image into a visual sensitivity image using a contrast sensitivity function filter. It was determined that the sum of the visual sensitivity values of the mura regions correlated strongly to the grades obtained by human evaluation.

1. Introduction

Mura is defined as non-uniformity of luminance and/or chromaticity on a display screen. It is still difficult to quantitatively evaluate mura because it occurs in a variety of shapes, sizes, edge gradients, and contrasts. A wide variety of different panel sizes are currently in production and the inspection viewing distance for such displays changes depends on the panel size. The evaluation results for a mura inspection depends on the viewing distances.

While previous efforts have been made to quantify mura, those efforts did not discuss the effect of the mura edge gradient [1, 2]. A separate report, however, showed that the human eye was capable of recognizing mura by edge gradient [3]. And, while there have been numerous efforts to extract mura, discussions related to mura grading have been insufficient [4].

In this paper, a method that evaluates the mura grade of FPDs using a filtered image by the Contrast Sensitivity Function (CSF) is presented. Problems related to the edge gradient effect of mura and the viewing distance variations are resolved by use of the CSF filter. Numerous sample images consisting of various contrasts, sizes and edge strengths are tested and comparisons are made between the CSF filter results and human sensitivity evaluation results.

2. Visual sensitivity

Figure 1 shows the CSF that was measured by one of the authors using an instrument (ViSaGe, Cambridge Research systems Ltd.). Since the CSF is a response function of human vision, the resulting image after CSF filtering represents the visual sensitivity of the image. The visual sensitivity value is the AC component response of human vision.

Figure 2 shows the conversion into the visual sensitivity from the original image. There are five mura in Figure 2 (a). The sizes and edge gradients of the mura are different, but their contrast is the same. Figure 2 (b) shows the result of CSF filtering viewed from 1.5 meters away from the display. Even though the mura contrasts are the same, the visual sensitivities are totally different due to the variety in mura edge gradients. The visual sensitivity value of mura No. 5, which exists in the right upper corner, is very weak compared with that of other mura. Table 1 shows detail of the features of the five mura.

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Edge</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>small</td>
<td>strong</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>small</td>
<td>strong</td>
<td>20%</td>
</tr>
<tr>
<td>3</td>
<td>medium</td>
<td>medium</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>medium</td>
<td>medium</td>
<td>20%</td>
</tr>
<tr>
<td>5</td>
<td>large</td>
<td>weak</td>
<td>20%</td>
</tr>
</tbody>
</table>
3. Mura grade evaluation model

The visual sensitivity $v_s$ is calculated by the following equation:

$$v_s(x,y) = F^{-1}\{CSF(u,v)I(u,v)\}$$  \hspace{1cm} (1)

where, $F^{-1}$ means Inverse Fourier Transform, $I(u,v)$ is Fourier Transform of Mura image $i(x,y)$, $CSF(u,v)$ is the Fourier Transform of contrast sensitivity function. The $CSF(u,v)$ is normalized at the maximum value of the contrast sensitivity. The viewing distance is considered in the calculation of Equation 1.

The value $v_s$ changes according to display luminance. So, visual contrast $Cv(x,y)$ is defined by Equation 2.

$$Cv(x,y) = v_s(x,y) / L_B$$  \hspace{1cm} (2)

where $L_B$ is the background luminance of the mura.

The total visual stimulus $S$ is calculated by the Equation 3.

$$S = \left\{ \sum_{x,y} (Cv(x,y) - Cvo) \right\}^{0.33}$$  \hspace{1cm} (3)

where $Cvo$ is the perceivable threshold of the visual contrast.

4. Human sensory evaluation

Mura samples of various contrasts, sizes and edge gradients of round shapes were generated using a mura generation software created for simulation experiments. Figure 3 shows the contrast, size and edge gradient definitions of the mura samples. Eight contrast types, 10 sizes and 13 edge gradient samples were each evaluated twice by 10 persons. Two 15 inches LCD monitors were used, one for the standard mura display and one for the test mura display. The evaluations were executed utilizing five grades ranging from -2 (good) to +2 (bad). The distance between observers and the LCD monitor was set at 1.5 m, and the average luminance of the displays was 100 cd/m².

Figure 4 shows human evaluation results. Figure 4 (a) shows the result of contrast change from 5% to 20%. The size and edge gradient are the same. It can be seen that human evaluation values did not vary much. Figure 4 (b) indicates that the results of size variation, contrast and edge gradients are the same. The human evaluation varies only 1 grade. Figure 4 (c) shows that the results of edge gradient variation, contrast and size are the same. However, human sensory evaluation values vary drastically according to the edge gradients.

5. Grading by visual sensitivity

The total visual stimulus value, which is defined by Equation 3, was calculated for mura samples at a viewing distance condition of 1.5 m. Figure 5 shows the relation between the total visual stimulus values calculated by simulation and the grades obtained by human evaluation.

The total visual stimulus is the sum of the visual contrast values that are greater than visual stimulus threshold. In this experiment the threshold value $Cvo$ is determined to be 0.4%. The total visual stimulus indicates a linear relation with the human evaluation results of the mura grade.

The mura patterns were also captured by a CCD camera. Figure 6 shows the results between the total visual stimuli and human evaluation grades. The images from the CCD camera were added 64 times to reduce random noises. The FFT processing resolution used was 512 x 512 pixels. The results of the real images were found to coincide with the simulation results for strong mura, but were not in agreement with the results for weak mura. This is because the stimulus values of the display background mura were added to the total visual stimulus values for the real images.

Figure 7 (a) displays an original image of a mura sample captured by the CCD camera. Figure 7 (b) shows the visual sensitivity image which was made by applying the CSF filter.

Figure 8 shows the result of a small defect evaluation. It is easy to extract a mura region by simple threshold technique. A reference image for subtraction is not necessary, because the luminance gradation that exists in real test images of FPDs are eliminated by the CSF filtering.
Fig. 4 Human evaluation results.

(a) Contrast variation

(b) Size variation

(c) Edge gradient variation

Fig. 5 Comparison of stimulus sum to human evaluation grade (Simulation).

Fig. 6 Comparison of stimulus sum to human evaluation grade (CCD camera).

(a) Original image   (b) Visual sensitivity image

Fig. 7 Example of visual sensitivity for a mura sample.
6. Discussion

SEMI introduced a metric Semu in 2002[1]. However, the Semu process only evaluates the contrast and area of the mura. In that proposal of Semu, the minimum contrast that can be perceived ($C_{jnd}$) was determined by regression analysis.

Figure 9 shows the relationship between the total visual stimulus values and $1/C_{jnd}$ for the 11 mura that were used to determine Semu, eliminating mura with widths of 1 and 2 pixels. By Figure 9, the total visual stimulus values of the mura are proportional to $1/C_{jnd}$. This indicates that the accuracy shown by the total visual stimulus value is equal to the accuracy displayed by the Semu evaluation technique. It should also be noted that the total visual stimulus criterion for mura evaluation has a wide range, and can be used to evaluate the mura that has edge gradients.

Fig.10 shows the effect of viewing distance to the total visual stimulus values. As the viewing distance becomes long, it becomes easier to recognize mura. So, the viewing distance is very important in inspections, because the stimulus values of the mura change according to the viewing distances.

7. Conclusion

We determined that mura grades can be estimated by the total stimulus value of visual sensitivity, which can be calculated by CSF filtering images. This novel method evaluates the edge gradient values that are inevitable when adapting the real FPD mura inspections.

The proposed method can be used to evaluate mura grades at any viewing distance simply by changing a calculation parameter because CSF data are determined by visual angles. We plan to conduct additional experiments using large FPD panels in order to further evaluate this novel method.

References